Omaha Public Power District
444 South 16th Street Mall
Omaha NE 68102-2247

October 28, 2005
LIC-05-0122

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555-0001

References:
1. Docket No. 50-285
2. Letter from NRC (Stephen Dembek) to OPPD (R. T. Ridenoure), Safety Evaluation For The Fourth 10-Year Interval Inservice Inspection Program Plan - Fort Calhoun Station (TAC NO. MB7241), February 19, 2004 (NRC-04-024)
3. The American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section V, Article 2, Mandatory Appendix VIII, "Radiography Using Phosphor Imaging Plate", as Published in 2004 Edition with 2005 ADDENDA

SUBJECT: Fort Calhoun Station Unit 1, Relief Request for Use of "Radiography Using Phosphor Imaging Plate"

Pursuant to 10 CFR 50.55a(a)(3)(i), OPPD hereby requests NRC approval of the Fourth Interval Inservice Inspection Program (Reference 2) incorporating "Radiography Using Phosphor Imaging Plate" in accordance with Reference 3. The details of the 10 CFR 50.55a request are enclosed.

OPPD requests approval by April 1, 2006 based on the need to perform the necessary procedure technique development and demonstrate the technology in time to support the 2006 Refueling Outage starting in early September, 2006.

If you have any questions or require additional information, please contact T. C. Matthews at 402-533-6938.

Sincerely,

H. J. Faulhaber
Division Manager - Nuclear Engineering

HJF/rlj

Attachments:

1. 10 CFR 50.55a Request
2. Supporting Information
3. "Phosphor Imaging Plate Technology" ASME Working Group White Paper

Attachment 1
Omaha Public Power District
Fort Calhoun Station Unit No. 1
10 CFR 50.55a Relief Request 10

Proposed Alternative In Accordance with 10 CFR 50.55a(a)(3)(i)

-Alternative Provides Acceptable Level of Quality and Safety-

1) ASME Code Components Affected

This request for relief is applicable, in part, to the following Class 1, Class 2, and Class CC components in the following systems:

Component	Class	Category
Reactor Coolant Piping System	1	B-J
Main Steam Piping System	2	C-F-2
Feedwater Piping System	2	C-F-2
Auxiliary Feedwater Piping System	2	C-F-2
Containment Liner	CC	E-A

This request for relief is applicable to the above identified piping systems at connections between (1) the safe ends of the steam generators or the pressurizer, and the piping; and (2) pipe-to-pipe connections or pipe-to-elbow connections within each system. This request is also applicable to the weld or welds restoring the containment liner boundary. In addition to the components listed above, the welds in other Class 1 and Class 2 piping systems may need restoration in support of these activities as well as other work planned for the 2006 Refueling outage. This request is also applicable to these components.

The original construction codes for the identified components are as follows:

Component	Construction Code
Shop fabrication of Reactor Coolant System (RCS) Loop Piping	B31.1-1955, Examinations were performed to ASME Section III with Winter 1967.
Installation of Reactor Coolant Piping	B31.1-1967, Examinations were performed Loop to ASME Section III, 1968.
Class 1 piping (Non-RCS) and Class 2 piping	B31.7, 1968, Draft.
Containment Liner	ASME Section VIII, 1968.

2) Applicable Code Edition and Addenda

Class 1 and Class 2 Piping Systems	ASME Section XI, 1998 Edition with addenda through the 2000 Addenda (1998-2000 Section XI Code).
Containment Liner	ASME Section XI, 1992 Editions with the 1992 Addenda (1992-1992 Section XI Code).

3) Applicable Code Requirement

Omaha Public Power District (OPPD) will replace the Fort Calhoun Station steam generators, pressurizer, and reactor vessel head during the Fall 2006 refueling outage. Paragraphs IWA-4150 of the 1998-2000 Section XI Code (IWA-4150) and IWA-4170 of the 1992-1992 Section XI Code (IWA-4170) require that OPPD identify a construction code for the installation of these components, as well as for the restoration of the containment pressure boundary that will be breached in order to allow OPPD moving the components into containment. The construction codes require, in part, radiographic examination of certain piping welds in the reactor coolant system, certain welds in the other Class 1 and 2 piping systems, and the weld(s) reestablishing the containment pressure boundary. This is a requirement to use film radiographic technology. OPPD is requesting permission to perform digital radiography (DR) using phosphor imaging plates (PIP) as an alternative to the use of film. This is an alternative to the requirements of IWA-4150 and IWA-4170. OPPD is proposing the alternative only for the capture and display of the radiographic images. Other than additional training for examiners in the principles and processes of DR, the elements of the radiographic examination process remain unchanged.

4) Reason for Request

Radiograph examination is an intrusive process that challenges the radiological controls of the plant with another radiation source. This results in additional personnel exposure and adds cost to the accomplishment of work. Because the PIPs are more responsive than traditional film to the radiation used in the radiographic examination process, DR significantly mitigates these two disadvantages. The exposure times for DR are reduced if typical film radiation sources are used. The exclusion zones required for DR maybe reduced, because DR may obtain satisfactory results with "weaker" radiation sources such as Selenium 75. A third reduction in the potential for exposure results because of the increased "dynamic range" of DR. ("Dynamic range" is the range of receptor exposure over which an image and contrast will be formed.) This property of DR decreases the potential need for additional images because of unacceptable exposures.

5) Proposed Alternative and Basis for Use

OPPD proposes as an alternative to the film radiographic techniques used to meet the requirements of the construction codes that the radiographic image be obtained on a phosphor imaging plate and presented for assessment by a digital image acquisition and display system in accordance with American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section V, Article 2, Mandatory Appendix VIII, "Radiography Using Phosphor Imaging Plate," as published in 2004 Edition with 2005 Addenda. Personnel qualifications will be updated in accordance with the primary construction code that will be governing the performance of the radiographic examinations, i.e., ASME Section III, 1992 Edition with no addenda. This will include the interpretation of the radiographic image as it will be presented in the digital format. No other changes to the radiographic examination process are proposed. The extent of examination (and re-examination) and the acceptance criteria will remain the same. As with film radiography, the examination procedures will need to successfully demonstrate the ability to obtain the required sensitivity based upon appropriate image quality indicators.

OPPD, based on information supplied by its primary contractor for installation of the major components during the 2006 refueling outage, is confident that DR, using phosphor imaging plates, will produce radiographic images that provide the acceptable level of quality and safety required by 10 CFR 50.55a(a)(3)(i). This confidence is based on not only the acceptance of the technology by ASME, which now allows DR for its applications, but also by the acceptance of the technology by the American Welding Society and the American Petroleum Institute. In addition, the primary installation contractor for the Fall 2006 refueling outage has evidence from previous field applications of DR that acceptable results can be achieved. These field applications applied DR to in-process radiographic examination of primary coolant piping (film radiography was used for record examinations) and for final examinations on piping systems not governed by the nuclear codes. Finally, this confidence will be proven by demonstrations that must satisfy the requirements of the ASME Code for resolution of image quality indicators over the applicable thickness ranges. This, of course, is the same deciding test that allows the use of film radiographic techniques.

6) Duration of Proposed Alternative

This alternative will be applicable to radiographic examinations performed as part of the Fall 2006 Refueling Outage.

Attachment 2

Supporting Information – Relief Request 10

Omaha Pubic Power District (OPPD) desires to utilize Digital Radiography (DR) during the Fall 2006 refueling outage for Fort Calhoun Station (FCS). During this outage, the following major components will be replaced: two steam generators, the pressurizer, and the reactor vessel head. These replacements require that Class 1 and Class 2 piping be severed. They will be restored in accordance with the requirements of The American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code (BPVC) Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components" (Section XI). In addition, the containment liner boundary will also be breached with a temporary opening to allow the removal and insertion of these major components. Section XI will also control the restoration of the containment liner boundary. (The OPPD Section XI Code date for Class 1 & 2 components is 1998 Edition with addenda through the 2000 Addenda. For Class CC components, the Code date is 1992 Edition with 1992 Addenda.)

In each case, the appropriate Section XI code requires that construction codes be selected to control the preparation, welding, examination, testing, and acceptance of the new components into the plant's systems, and the restoration of the containment liner boundary. The radiographic examinations of all but the containment liner will be performed to the requirements of ASME Section III, 1992 Edition, with no addenda. The containment liner radiographic examinations will be performed to the requirements of ASME Section VIII, 1968 Edition. The extent of examination (and re-examination), and the acceptance of the results will be governed by the applicable construction code. Also governed by these codes is the actual technique for performance of the radiographic examination.

OPPD proposes as an alternative to the technique requirements of these construction codes that the performance of the radiographic examination be in accordance with ASME, BPVC, Section V, Article 2, Mandatory Appendix VIII, "Radiography Using Phosphor Imaging Plate," published as part of the 2004 Edition with 2005 Addenda. Personnel qualifications will be updated with additional training in the principles and application of DR. This will include the interpretation of the radiographic image as it will be presented in the digital format. This alternative will not apply to the fabrication of the major components. All off site fabrication of the major components will be accomplished by use of film radiography.

The ASME BPVC published two revisions as part of its 2005 Addenda that now allow and control the use of radiographic examinations using phosphor imaging plates (PIP). This is commonly referred to as either Digital Radiography (DR) or Computer Radiography.

One revision was to paragraph IWA-2231 of Section XI. Prior to the 2005 Addenda, IWA-2231 did not allow the use of PIP as an image recording device. IWA-2231 now only requires that the radiographic examinations be performed with either X-ray equipment or radioactive isotopes and

the procedure comply with Article 2 of Section V. It is not obvious from the text, but the change was to allow the use of PIPs. A review of the Section XI documentation associated with the change clearly shows that the use of PIPs was the motivating factor. The action documenting the change to IWA-2231 is recorded in the ASME archives as Code Action BC04-1569. The ASME archival record is not normally released, but ASME agreed to the release of the following information in support of this OPPD request for relief. The "Subject" field of BPVC record BC04-1569 states, "IWA-2231 Radiography using phosphor imaging plates." The "Proposal" field states "Change IWA-2231 to allow radiography using phosphor imaging plates." The "Explanation" field states, in part, the following:

> *The following Code change, omitting reference to film radiography, allows radiography to be performed using phosphor imaging plates when requirements are published in Section V, Article 2. IWA-2231 states in part "...For radiographic examinations employing either X-ray equipment or radioactive isotopes and photographic films, the procedure shall be as specified in Article 2 of Section V." At this point there are no requirements for phosphor imaging plate radiographs. However, action is proceeding in ASME Section V, Article 2 (BC03-1548) and their Code Case 2476 and this Code revision provides for accelerated implementation in Section XI.*

(While the Subject, Item and Explanation fields of BC04-1569 were not part of the voted action and were not subject to the full consensus process, OPPD considers that the statements make clear the reason for the revision of IWA-2231.)

The revision of Article 2 of ASME BPVC Section V, "Nondestructive Examination" (Section V) (that is being referenced in Section XI action) is the second applicable revision published in the 2005 Addenda. This revision adds Mandatory Appendix VIII – "Radiography Using Phosphor Imaging Plate" (MAVIII) to Section V. Requirements for the use of PIPs as an alternative to film radiography are delineated in MAVIII. Mandatory Appendix VIII modifies the requirements of Article 2 as appropriate to accommodate the differences between film and DR radiography examination. Unless modified by MAVIII, all provisions of Article 2 are requirements for the implementation of DR. This also requires that the implementation of DR follow the requirements of Mandatory III, "Digital Image Acquisition, Display, and Storage for Radiography and Radioscopy," and Mandatory Appendix IV, "Interpretation, Evaluation, and Disposition of Radiographic And Radioscopic Examination Test Results Produced by the Digital Image Acquisition and Display Process," as they may apply.

The White Paper prepared by Section V, attached, supports this discussion and was prepared to provide the technical justification to the ASME consensus process to accept the proposed changes. The White Paper provides a technical discussion of the technology, as well as some history of its acceptance in related industries. It is provided for NRC use as part of the justification for utilizing DR and PIP technology.

As with film radiography, a written procedure is required by Section V for implementation of DR. In addition to the elements of a normal film radiography procedure, the DR procedure must also identify the phosphor imaging plates by manufacturer. It is also required that the image

scanning, and processing equipment manufacturer and model be identified. MAVIII requires that each DR examination procedure demonstrate its ability to identify the required image quality indicators (IQI) to the same acceptance criteria required of film.

One of the significant characteristics of most digital radiographic receptors is that they have a wide dynamic range. This is the range of receptor exposure over which an image and contrast will be formed. Digital radiographic receptors produce usable digital data over a wide range of radiation exposure values. Comparatively, radiographic film has a somewhat limited dynamic range. Because of the dynamic range of the digital radiographic examination technology, the concept of density as applied to film RT technology is not utilized. However, MAVIII requires additional IQIs when the image spans more than one thickness range. In fact, MAVIII requires an IQI for each thickness range.

OPPD is confident that DR, using phosphor imaging plates, will produce radiographic documentation that provide the acceptable level of quality and safety required by 10 CFR 50.55a(a)(3)(i). This assurance is based on not only the acceptance of the technology by ASME, which now allows DR for its applications, but also by the acceptance of the technology by the American Welding Society and the American Petroleum Institute (see Attachment 3, page 7). In addition, the primary contractor for installation of the major components during the 2006 refueling outage has evidence from field applications that DR is a viable field technology. The DR technology was used for in-process radiographic examination of primary coolant piping (film radiography was used for record examinations) and for final examinations on piping systems not governed by the nuclear codes. (These field applications did not involve OPPD.) Finally, this confidence will be proven by demonstrations that will meet the requirements of the ASME Code for resolution of image quality indicators over the applicable thickness ranges. This, of course, is the same deciding test that allows the use of film radiographic techniques.

Attachment 3

"Phosphor Imaging Plate Technology", White Paper Final Document, ASME Working Group on Phosphor Plate Radiography, Task Group on Imaging Plate Radiography, October, 2004

Phosphor Imaging Plate Technology

ASME Working Group On Phosphor Plate Radiography
Task Group On Imaging Plate Radiography

Executive Summary

Real-time, near real-time, and phosphor imaging plate techniques were evaluated throughout the course of the project. The storage phosphor technique and a Selenium-75 (Se^{75}) radiation source currently offer the most promise of useful implementation. Storage phosphors can acquire the digital image with significantly less radiation exposure than convention film. Se^{75}, having a lower radiation energy value, is able to provide the necessary exposure while allowing smaller radiation exclusion zones. Reducing the radiation exclusion zones allows more adjacent work to continue uninterrupted.

The use of a storage phosphor, which closely resembles conventional film, does not require a significant amount of training for a "film" radiographer to learn to use. This can greatly ease implementation and is of worthy note when considering widespread use of the system. The role of analytical X-ray inspection acts as an early warning system as it affords manufacturers, in a reliable and cost-effective manner, the luxury of getting the much-needed feedback with regard to an industrial process for proactive process control. This is an added benefit to digital imaging systems providing immediate feedback.

1.0 *Introduction*

In radiography, as with other areas of NDE, no one method or technique will serve all situations or needs. There are a number of factors to be considered when evaluating a radiographic imaging system beginning with the size, shape, and flexibility of the sensor. The contrast sensitivity or gray scale range (e.g. 8 bit versus 12 bit), and resolution (pixel size) are major factors in determining the imaging performance and scan rate. All these factors must be traded off against size, mobility, and cost.

There are available today a variety of radiographic inspection choices including conventional film, real or near-real time, computed tomography, and phosphor imaging.plate. Each has their own advantages and disadvantages depending on the environment and types of flaws sought.

1.1 Description of Planned Activities – Objectives

A vast percentage of project activities were focused on the accumulation of image data utilizing varying radiation sources and imaging media. An overall objective included evaluating this data in terms of meeting code image sensitivity requirements, reducing radiation exclusion zones, and data file evaluation. It was determined that once the threshold where code required sensitivity could be attained (for each type of radiation & energy) it will be possible to plot data and draw conclusions as to what industrial environments (piping diameter & wall thickness) the practice is best suited for, and what environments warrant a further look at exposure technique enhancements.

The introduction of Selenium 75 (Se^{75}), which recently received Nuclear Regulatory Commission (NRC) approval for the performance of industrial radiography, allows for advances in film-less imaging while maintaining the portability of an isotope.

1.2 Technical Path

The technical portion of the project is considered to be the actual "hands-on" accumulation of exposure image data and image evaluation. Other components of the project such as evaluation of code requirements and implementation assessment are not considered as a "technical" aspect of the summary.

Exposure trials using (1) Iridium-192 radiation energies, (2) Selenium-75 radiation energies, and (3) varying energies of X-Radiation were made.

As an activity prerequisite, it was necessary to determine the need for joint configurations and procure piping sections of specific diameter and wall thickness to reflect those configurations common to radiography projects and piping specifications.

To allow for thorough evaluation of image quality, extensive exposure data was collected. As design and fabrication codes typically allow the use of plaque-type or wire-type Image Quality Indicators, it was necessary to acquire the essential hole or wire sensitivity data for exposure arrangements provided for in ASME V, Article 2 (Nondestructive Examination / Radiographic Examination). Image quality data was recorded for all exposure techniques (elliptical, panoramic, or double-wall contact) and kept in other documents to show final assessment of radioscopic technique adequacy. Knowing the achievable sensitivity thresholds for certain piping joint configurations will allow for the use of a radioscopic imaging system on a project where all piping examinations were within specific diameter and thickness parameters.

The introduction of Selenium 75 (Se^{75}), which recently received NRC approval for the performance of industrial radiography, was cause for deviation from the originally planned path. The radiation energy values for Se^{75} showed potential for improved image quality while at the same time allowing for the performance of radiography within a smaller radiation exclusion area. Se^{75} has a radiation energy spectrum very conducive to producing near X-ray quality images in moderate thickness piping joints. As Se^{75} is housed in conventional exposure devices, no altered requirements for the installation of gamma ports are necessary. Thus, Se^{75} was incorporated into the initial scope to allow for evaluation, as it was believed that this could provide one of the greater benefits of the project.

2.0 *Brief Radiation Tutorial, History & Background of Digital Radioscopy*

Differences between traditional film radiography and phosphor imaging plate are similar to the differences between a photographic camera and a camcorder. Radiography with film is a time consuming technique; the technician must perform many operations to produce and interpret an image. Among these steps is handling of the film in a darkroom both prior to and after the X-ray exposure (which itself may require up to several minutes). The end result is a "snapshot" of the object of interest that must typically be viewed on a high intensity light box under subdued general lighting conditions. Post processing of the image is generally limited to adjusting the intensity of the viewing light. Long-term storage, duplication or distribution of a film based image are also problematic, time consuming and expensive. A film-based system must include a budget for consumable items, film and chemistry, and provide for the disposal of hazardous waste.

Radioscopy on the other hand uses electronic sensors to convert the radiation energy into a video or directly to a digital format. The image can be presented on a computer monitor almost instantaneously, hence the name "real-time" or "near real-time" radiography is commonly used. The technician may view the still image as with film, or may even watch an in-motion image. Processing this image is done electronically with a special-purpose computer. The technician can adjust not only the brightness of the image, but also the contrast, apply filters to reduce noise or "snow", enhance edge detail, and quickly and precisely measure any details of interest in the image.

2.1 "Quality" of Radiation, Radiation Sources

The radiation source, whether isotope or X-ray generated, plays an important role in the performance of digital imaging. The radiation source must be balanced against the type and thickness of material undergoing examination. Ideally, a lower energy source is used for the given material thickness to minimize detrimental effects to the image. Higher energy radiation decreases image latitude and overall image quality. An X-ray tube, where the parameters affecting radiation generation are variable, produces the most desirable image. Unfortunately, the use of X-ray tubes is not always feasible in the field. Thus, the choice is limited to the most feasible isotope source. When using film, Cobalt-60 (Co^{60}) is used for exposure of thicker items, and traditionally Ir^{192} is used for lesser thickness. Coinciding with this project, however, was the

advent and use of Se^{75} for use in the US for industrial radiographic purposes. Se^{75}, because of its inherently low and monochromatic radiation spectrum, promises to play a valuable role in the future of radiographic examination.

X-radiation, because the input voltage can be constant and of monochromatic wavelength, produces better imager quality than an isotope radiation source. This is because isotopes have energy spectrums of varying peaks. Unfortunately, because of the often-constrained environments in which radiography must be performed, X-ray tubes do not consistently offer the universal radiation source "solution". Thus, it is necessary to perform a great deal of exposures in the field with an isotope source.

2.2 Isotopes (Cobalt^{60}, Iridium^{192}, Selenium^{75})

Enrichment reactors have made available a whole family of radiation-emitting materials, which have advantages of portability and penetrating capability over X-rays and are not dependant on a power supply. Some of the notable disadvantages pertain to their low quantity of radiation output, the inflexibility of their penetrating power while making adjustment to suit the item to be penetrated, and the underlying hazard they pose to the health of personnel. These disadvantages, however, do not mean that radiographers have stopped using radioisotopes. Only radioisotopes can perform the job in many applications of radiography as in the case of inspection without access to electric power.

3.0 *Tutorial, Photo-Stimulable Storage Phosphor Digital Radiographic Imaging*

The second is a phosphor imaging plate technology. In this technology, a latent image is held on the imaging media until scanned with a laser. The direct capture method employs a matrixed semiconductor array. Both technologies are described in this report. In addition, some of the ways that digital radiography can be employed to better identify and diagnose indications as compared to film are described.

Since phosphor imaging plates are linear over a much greater practical range than with film, they exhibit a wider exposure latitude. In many cases this can permit either shorter exposures or a much wider range of thickness to be imaged in a single exposure. Therefore, an image of moderate quality can be obtained in a short time to reduce exposure, while a longer exposure time could also be used with the same screen to produce an image with higher quality.

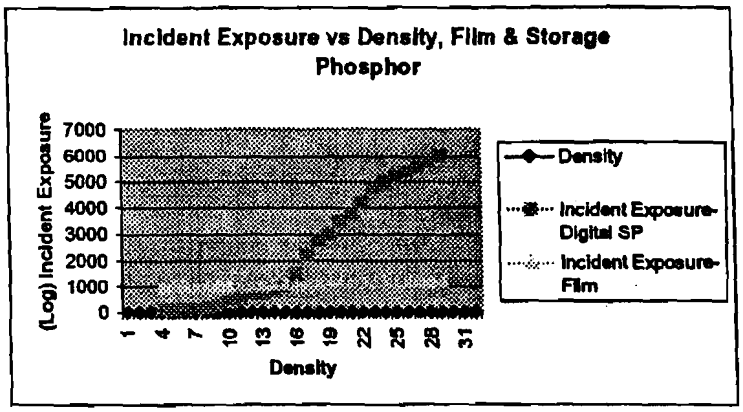
The phosphor imaging plate systems dynamic range, which varies by the detector and by the application, limits the contrastive performance of any detector. The dynamic range of the system is generally believed to be the number of bits in the detector or the number of bits devoid of the read-out noise. However, it also represents the bit depth minus readout noise in a particular area of the image and minus the background scatter signal in the system.

Spatial resolution is the size of the smallest detail that can be seen with an imaging system, and is primarily limited by the size of the pixels in the detector.

Traditional radiographic imaging media exists to replace film, but still uses similar cassette techniques, known as a "phosphor imaging plate" technique. The imaging plates are placed in a cassette similar to film and can be used with lead or other suitable intensifiers for various applications. Phosphor imaging plate radiography systems employ an imaging screen containing storage phosphor crystals to capture a latent radiation image. The phosphor grains are coated on a flexible substrate and store the incident radiation energy in the form of trapped electrons thus the name phosphor imaging plate. Unlike film, however, the number of trapped electrons is linearly related to the input radiation intensity pattern. Part of the incident radiation is absorbed by the phosphor imaging plate and electrons from a luminescent center are excited into trapping sites. Readout of the latent image can be accomplished by laser stimulation at an appropriate wavelength resulting in the emission of visible light (luminescence) from the phosphor grains. This process is referred to as photo-stimulated luminescence, or PSL. The incident laser stimulates the trapped electrons back to the luminescent center and gives off visible light in the

process. Since the luminescence is correlated to the latent image, it has the intensity pattern of the original radiation image. In this way, the storage phosphor acts as an energy transducer, converting the radiation pattern to a visible light pattern.

Figure 1



The above chart depicts how film reacts versus a storage phosphor. To achieve the required image density with film, a very narrow margin exists for the required exposure. With the storage phosphor, a much larger margin for exposure exists where the required density can be maintained. While being able to display wide image latitude, this also is valuable as "re-shoots" can be avoided when there is less margin for exposure time error.

A ≤ 50-micron laser is utilized to scan the storage phosphor screen. While the laser is scanned across the screen at a constant velocity, PSL is generated along this line to achieve a two-dimensional readout.

Another primary consideration is the flexibility of the screen and cassette, allowing them to be placed in small, curved areas as is typical of piping joint configurations. Finally, though the scanning process removes some of the stored image information, it does not remove all of it; an erase step is required before the screen can be re-used. The erasure time varies with exposure conditions, but typically takes less than 60 seconds. Erasing can be performed as a separate step external to the scanning device where the user has control over the actual erase time.

In cases where field applications have limited access and power is not convenient, phosphor imaging plate technology clearly has significant advantages. Since a laser is employed for PSL generation, the smallest detail that can be resolved will be equal to or larger than the laser focal spot size. The smallest resolvable element is referred to as a pixel and is defined by the product of laser scan velocity and the sampling period.

4.0 Code Requirements and Digital Imaging

Questions commonly arise on the "code compliance" aspect of Digital Radioscopy for two primary reasons.

First, one must re-acclimate from a "film-culture" to "phosphor imaging plate". If the phosphor imaging plate image analyst thinks in terms of conventional film exposure, certain provisions of fabrication codes may seem hard to meet. For instance, in phosphor imaging plate radiography, because the phosphor imaging plate looks like and is handled like film, a first reaction is to think the phosphor imaging plate is merely a "film substitute". This is not the case. A phosphor imaging plate is merely a temporary storage device for an electronic charge, similar to a battery. The phosphor imaging plate is energized during exposure on the part or component, and transported to the laser reader where the energy is released and converted to light, whereupon digitization can occur. Thus, while the phosphor imaging plate may physically resemble film, it has no value for long-term archival.

Secondly, another cultural factor can be the resistance of a workforce to emergent technologies. Often, one acquires a specific set of skills and becomes comfortable with performing associated tasks based upon this set of skills. To drastically change the way work is performed requires a complete learning of new skills. As phosphor imaging plate technology requires a high degree of computer proficiency, part of the workforce may resist just because of a lack of computer skills.

Since various digital imaging systems exhibit different response characteristics (i.e., different latitudes), a step wedge can be useful in establishing the system dynamic range either during system evaluation, during set up, or as part of routine inspection. Since each of these factors is affected by a variety of controllable variables in digital imaging, some degree of technique development may be necessary to produce the most effective results. Image density, or in "film" terms, is the degree of blackening. In the case of phosphor imaging plates, it can be thought of as a point on a gray scale. The images of the phosphor imaging plate system can be digitized at 12 bits (log)and produce gray scale levels from 0 to 4095. For convenience, they are divided by 1000, resulting in relative digital density values from 0 to 4. This provides a mean comparison to traditional "film" density values. The readout process gives rise to one of the major differences between phosphor imaging plates and film and that is the difference between optical and phosphor density. Unlike film, the exposure of phosphor imaging plates is linear (film would have a characteristic curve). Thus, where image sensitivity is verified at the maximum thickness of the part or component being radiographed, the verification can be considered suitable for the full viewing dynamic range, at all other thickness'.

Numerous fabrication codes have recognized the importance of phosphor imaging plate technology to the industry and incorporated provisions for such viewing techniques. A list of important references and information sources can be found in Attachment 1. There are also additional parameters that are not normally measured in film radiography and can be important in phosphor imaging. For example, it is not standard practice to measure film resolution; in the case of both phosphor imaging plates and direct capture methods, however, it has been shown that resolution can impact a wide variety of implementation issues, including throughput and cost.

4.1 American Society of Mechanical Engineers (ASME)

Article 2 addresses "in-motion" radiography, but lapses are present regarding the performance of imaging with phosphor imaging plates.

4.1.1 Justification For Radioscopic Imaging

It is the opinion of the authors that (1) the means exist to produce radiographic images equal to those produced with film, and that (2) this can be demonstrated to the satisfaction of the Inspector, by means of a written procedure.

Some key excerpts from ASME V, Article 2 are copied following for reference purposes.

APPENDIX II — REAL-TIME RADIOSCOPIC EXAMINATION

II-210 SCOPE; Real-time radioscopy provides immediate response imaging with the capability to follow motion of the inspected part. This includes radioscopy where the motion of the test object must be limited (commonly referred to as near real-time radioscopy).

Real-time radioscopy may be performed on materials including castings and weldments when the modified provisions to Article 2 as indicated herein are satisfied. SE-1255 shall be used in conjunction with this Appendix as indicated by specific references in appropriate paragraphs. SE-1416 provides additional information that may be used for radioscopic examination of welds.

APPENDIX III — DIGITAL IMAGE ACQUISITION, DISPLAY, AND STORAGE FOR RADIOGRAPHY AND RADIOSCOPY

Digital image acquisition, display, and storage can be applied to radiography and radioscopy. Once the analog image is converted to digital format, the data can be displayed, processed, quantified, stored, retrieved, and converted back to the original analog format, for example, film

or video presentation.

Digital imaging of all radiographic and radioscopic examination test results shall be performed in accordance with the modified provisions to Article 2 as indicated herein.

Complete DRT viewing system performance check must be established. I.e. if the monitor was not capable of displaying the sensitivity of the data file, the technique would be performing at far less than optimum.

APPENDIX IV — INTERPRETATION, EVALUATION, AND DISPOSITION OF RADIOGRAPHIC AND RADIOSCOPIC EXAMINATION TEST RESULTS PRODUCED BY THE DIGITAL IMAGE ACQUISITION AND DISPLAY PROCESS

IV-210 SCOPE; The digital image examination test results produced in accordance with Article 2, Mandatory Appendix II, and Article 2, Mandatory Appendix III, may be interpreted and evaluated for final disposition in accordance with the additional provisions to Article 2 as indicated herein.

The digital information is obtained in series with radiography and in parallel with radioscopy. This data collection process also provides for interpretation, evaluation, and disposition of the examination test results.

4.2 American Welding Society (AWS)

Recent editions of AWS D1.1 (Structural Welding Code - Steel) have acknowledged the use of digital imaging methods and require written procedures for the performance of such. Procedures can be developed and issued for radioscopic imaging performed to meet the requirements of this code.

4.3 American petroleum Institute (API-1104)

This edition of API 1104 (Welding of Pipelines and Related Facilities, 19th Edition) has acknowledged the use of digital imaging methods and requires written procedures for the performance of such. Procedures can be developed and issued for radioscopic imaging performed to meet the requirements of this code.

5.0 *The Phosphor Imaging Plate*

5.1 The Data File / Image File Format

Storage, duplication, and distribution of phosphor imaging plate images is simple, quick, and inexpensive. Mass storage of images for archival purposes is also simpler and cheaper. For example, a single removable cartridge similar to a CD can store hundreds of images, the equivalent of several boxes of film, with an archival life of more than 100 years.

5.2 Is The Data Secure and Tamper-Proof?

Since the onset of digital imaging, this is a very commonly asked question. One must bear in mind that a great deal of the phosphor imaging plate technology has evolved from the medical industry. File protocol formats have been established in which the original, unedited data exists for the record. Data is recorded in unprocessed form, or as required by examination system performance characteristics. The original data set is included in the data report and record.

Software used for phosphor imaging plate technology is typically Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) compliant. DICONDE file format is further addressed in ASTM E 1475-02 and therefore not further detailed in this report. In short, tamper-proof data file protocol is in place and this should not be a concern for the implementation of phosphor imaging plate use.

5.3 Phosphor Imaging Plate Processing

Image processing offers the possibility of sharper contrast and improved visibility of edges, lines, details, and other features. While no information is added or subtracted in the process,

enhancement can make the information more easily viewed and more understandable.

Histogram equalization is the redistribution, or mapping, of digital image values so that all gray scale intervals will contain an equal number of pixels. This is a useful method when a wide range of densities is acquired or if the image contrast is shallow. It helps to improve the visible contrast in low contrast objects.

5.4 Image / Data File Retention

Whereas a film "viewer" provides direct access to the viewing of a radiograph, the viewing "media" for the phosphor imaging plate data file may be a licensed software application. The application may be purchased externally, and may need to be licensed for exclusive use. In order for Client personnel to maintain a position to "overview" the results of examinations, licensed copies of the software may need to be purchased. A single copy would enable the cognizant Client/Owner oversight individual to perform the "overview" but would not allow for off-site input if it were to become necessary. The purchase of licensed copies of the phosphor imaging plate data analysis software would likely be required.

5.5 Application of Code Acceptance Criteria

A valuable benefit of digital imaging techniques is the ability to provide immediate feedback to fabrication processes such as welding. Thus, the technique provides for process control. As is often the case with film radiography, this feedback is not received for 24 hours. At this point the value of process control is lost. If a recurring welding problem were present, the subsequent repairs would not have been avoided, as they would have with a technique providing immediate feedback. With a phosphor imaging plate imaging technique, the welding could have been stopped until trouble-shooting measures initiated. To enhance the final examination process, it is critical that weld quality evaluation times are held as low as possible.

An evolving methodology that should be monitored is Automatic Defect Recognition (ADR). This is a software enhancement that allows for defect recognition and evaluation. Thus, in the future it may be possible to complete component acceptance automatically, with only a periodic "human" oversight function performed. While this may seem like something quite a way "down the road", it is necessary to point out that this methodology is currently being used successfully by several large automotive parts manufacturers.

Useful References

- ASME V, Article 2, Radiographic Examination (2001 Edition)
  - Appendix I; In-Motion Radiography
  - Appendix II; Real-Time Radioscopic Examination
  - Appendix III; Digital Image Acquisition, Display, and Storage For Radiography and Radioscopy
  - Appendix IV; Interpretation, Evaluation, and Disposition of Radiographic and Radioscopic Examination Test Results Produced by the Digital Image Acquisition and Display Process
- ASTM "Standardization News", October 2000 (Committee E07 Addresses Universal DRT Data File Format)
- ASTM E 1475-02; Standard Guide For Computerized Transfer of Digital Radiological Examination Data
- ASTM E 1000-98; Standard Guide For Radioscopy
- ASTM E 1255-96; Standard Practice For Radioscopy
- ASTM E 1416-96; Standard Test method For Radioscopic Examination of Weldments
- AWS D1.1; Structural Welding Code – Steel, 2002 Edition
- API 1104 (19th Edition); Welding of Pipelines and Related Facilities

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